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A Stripper Well Consortium Report

Establishing Programs to Reimburse Operators for Produced Water Desalination

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Texas Water Resources Institute

Table of Contents

Establishing Programs to Reimburse Operators for Produced Water Desalination

List of Tables and Figures

Establishing Programs to Reimburse Operators for Produced Water Desalination

Executive Summary

Management and disposal of produced water is one of the most challenging problems associated with the oil and gas industry. Very large volumes of produced water are produced along with the oil and gas resources. Handling produced and injected water is a major emphasis in the industry today, both in mature oil leases and in newer production from unconventional gas reserves such as coal bed methane (CBM). The treatment of wastewater, its effects on the environment, and a growing concern for the availability of water in arid lands is no longer just an engineering issue but is no a social issue as well.. Current brine management methods, such as re-injection of the produced water back into the reservoir is often not an option. Other methods such as impoundment and re-use for beneficial purposes are costly to the industry, a concern to the environmental community, and a headache to the regulatory bodies responsible for oversight. .

The first Stripper Well Consortium (SWC) project funded at Texas A&M University was *“Environmental and Regulatory Issues Relating to the Utilization of Produced Water from Oil & Gas Operations*”, a study of the existing policies of two oil and gas producing regions. With the support of the SWC, A&M developed guidelines for companies to follow for making this new source of fresh water available for productive use. We met with appropriate agencies as new rules and regulations were being considered and worked with those seeking to remove some of the roadblocks to the re-use of treated produced water.

The first project addressed regulatory practices that are encountered when developing a produced water reuse program. This second project focuses on economic incentives to reimburse operators who choose to re-use produced water for beneficial purposes. It is a part of the overall A&M program to promote the beneficial re-use of produced water resources from oil and gas operations.

The goal of this second SWC project has been to identify market mechanisms to repay those willing to develop this new and unconventional source of fresh water. Our work includes (1) upgrading existing prototype units, (2) operating short and long-term field testing with full size process trains and (3) identifying practices in which environmental and oil and gas regulatory agencies can reimburse those who adopt such practices.

Testing at A&M has included extended testing in “field laboratories” to gather much needed extended run time data on filter salt rejection efficiency and plugging characteristics of the process train. This information is needed by operating companies and regulatory agencies when they consider their support for a significant, if unconventional, new source of fresh water resources.

Results of Project

Our program has been well received by industry and the government. We have successfully demonstrated that produced water can be treated at less expense than transporting it to commercial disposal wells off-site. We have worked with private companies and public agencies to identify reimbursement mechanisms, in effect how to receive value for this new found resource.

In Texas, Governor Perry and the Texas Water Development Board (TWDB) have been providing leadership for the state in developing desalination programs, including treatment of waste water and oil field brine. However, environmental and regulatory issues related to desalination of produced water in Texas clearly inhibit technology advancement of this resource. Cost reduction advancements in technology are slowed by a lack of a clear "path to market" of new products and processes. It is hoped that this SWC project will add a different perspective to discussions about water sources for desalination, conveyance issues associated with water transfer, and the demand for the resource if it were to be made available.

Local issues that communities would identify as barriers must still be addressed at the local level. Barriers include the perception that desalinated produced water is not pure enough for consumption by humans or livestock and that there might be environmental drawbacks to its use for plants, range, and habitat sustainability. Advanced technology and an improved regulatory climate is improving the likelihood of adoption of produced water desalination by water use groups in the state.

The Texas A&M program is sponsored by the Stripper Well Consortium (SWC), the Global Petroleum Research Institute (GPRI), and by the Texas Water Resources Institute (TWRI) It is also endorsed by the Texas Railroad Commission, the agency responsible for regulating the oil and gas industry in Texas and the Texas Water Development Board.

Establishing Programs to Reimburse Operators for Produced Water Desalination

Section 1

Background and Previous Work

Management and disposal of produced water is one of the most challenging problems associated with the oil and gas industry. Very large volumes of produced water, or brine, are produced along with the oil and gas resources. Handling produced and injected water is a major emphasis in the industry today partly to the increasing importance of coal bed methane (CBM). The treatment of wastewater, its effects on the environment, and a growing concern for the availability of water in arid lands is no longer just an engineering issue but is no a social issue as well.. Current management methods available, such as re-injection of the produced water back into the reservoir is often not be an option. Other methods such as impoundment and re-use for beneficial purposes are costly to the industry, a concern to the environmental community, and a headache to the regulatory bodies responsible for oversight. .

Texas has long been one of the top petroleum producing states in the nation. As fields have matured, more brine water is produced along with the petroleum resource. More brine water is being re-injected as well, to sustain production, prevent subsidence, and to dispose of excess produced brine. It is ironic that Texas has long been struggling with a lack of water resources too, especially in West Texas. As the population of the state grows, more demand be being placed upon surface and ground water sources of fresh water. Why hasn’t produced water been used as an additional source of water?

The simple answer is that untreated produced brine has contaminants that make it unpalatable for humans or livestock. Re-injection of the brine back into the formation from where it was produced has been the least expensive; hence preferred disposal method for brines. Large quantities of produced water are brought to the surface in Texas as a result of various natural resource extraction activities. The composition of this produced fluid is dependent on whether crude oil or natural gas is being produced and generally includes a mixture of either liquid or gaseous hydrocarbons, produced water, dissolved or suspended solids, produced solids such as sand or silt, and injected fluids and additives that may have been placed in the formation as a result of exploration and production activities.

The Texas A&M desalination program, sponsored by the Texas Water Resources Institute (TWRI) is seeking to determine whether desalination of produced brine offers promise as a source of fresh water resources. Research is currently underway at a number of companies to assess the economic and technological feasibility of desalting this product water to develop water of sufficient quality to meet certain local water supply needs and to allow consideration of disposal options other than well injection. With the assistance of the Stripper Well Consortium (SWC) we are working to further the technology and put it into commercial practice.

Specific research needs are harder to prioritize. For the past three years A&M has worked to find technologies to employ in desalination and to outline ways to establish a value for the resource that is recovered by this treatment. The group (led by this author) unequivocally states that the technology is available to desalinate certain brines produced in petroleum operations. However that technology needs to be improved, the value of fresh water and local water supply needs must be established, and the environmental and regulatory issues associated with beneficial use must be addressed.

Produced Water Management in Oil and Gas Industry

In the oil and gas industry, standard water management operations include handling large volumes of produced brine. These operations offer a novel and unique approach to re-injection of saline RO concentrate from the desalination process into oil and gas producing zones.

Oil and gas operations produce copious amounts of brine water along with the associated petroleum resource. Produced water, (any water that is present in a reservoir with the hydrocarbon resource) is produced to the surface with the crude oil or natural gas. The oil and gas industry is experiencing increased volume of produced water handled in both onshore and offshore petroleum production operations. The resulting operational costs and environmental issues are becoming a major concern, especially with the possibility of further reduction in the oil content allowed in the discharged water (offshore operations) , as well as the fact that produced water contains a number of undesirable toxic components. Figure 1 shows a slide from Shell Oil Company on that company's production of brine worldwide in the past decade[1].

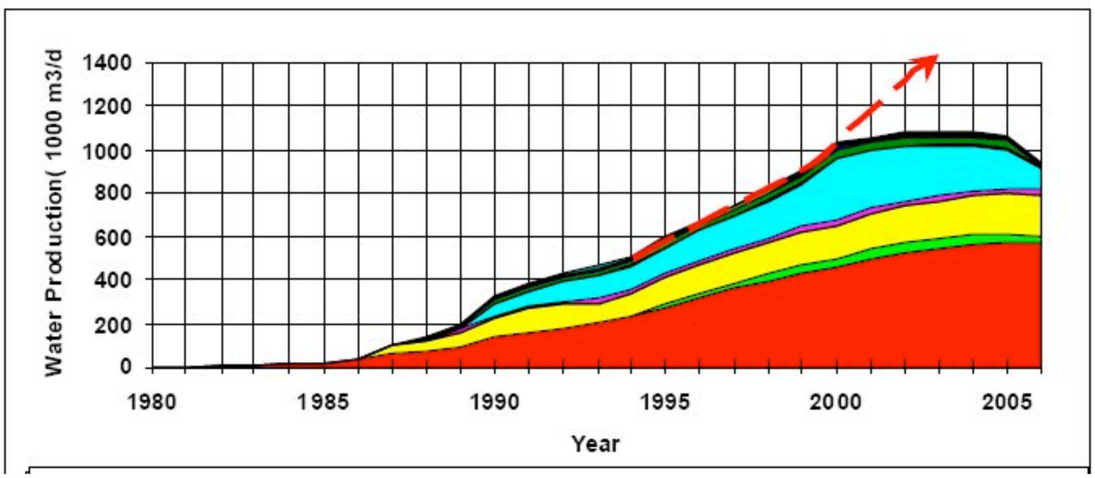


Figure 1 shows oil field produced water volume trends in each of the five major operating areas for Shell Oil. (1,000 m^3 = 6289 bbls). The trend increases in each of the areas until (assumed) new technology can intervene.

For the United States, the American Petroleum Institute estimated about 18 billion barrels per year were generated from onshore wells in 1995, and similar volumes are generated today. Offshore wells in the United States generate several hundred million barrels per year of produced water. Internationally, three barrels of water are produced for each barrel of oil. Production in the United States is more mature; the U.S average is about 7 barrels of water per barrel of oil. Closer to home, in Texas the Permian Basin averages more than 9 of water per barrel of oil and represents more than 400 million gallons of water per day processed and re-injected[2]. New technology is needed to forestall these trends.

To speed up the adoption of new technology, the industry is gradually adopting new technology for handling produced water both in mature fields and in new and planned developments. Innovative programs take into consideration the nature of the water, technology limitations, both emission to the atmosphere and discharges into the sea, nature of the discharges, safety concerns and cost, as well as establishing any environmental gains in each case. In this procedure companies such as Shell use a systematic empirical ranking and indicator tool applied to the different aspects of the alternative options considered. Most operators, big and small handle produced water management in the same way. Most often in Texas however, the option is brine injection back into the producing formation.

In another industry, lack of water is the critical factor. A water crisis is looming in many parts of the United States. Areas in the American West and Southwest are especially critical, with many areas currently coping with a series of droughts that have significantly altered land-use behavior and impacting both urban and rural communities. Throughout these regions, water quantity and quality issues increasingly are being recognized by state policy makers, local elected officials, and the citizenry at large. In Texas, data available from the Texas A&M Cooperative Extension[3] (TCE) show the pervasiveness of these concerns in the state (TCE 1999). In 1999, TCE, in a major planning effort, gathered information from over 10,000 Texas residents on critical issues confronting their communities. Those issues associated with water quantity and quality ranked among the top five priorities in 184 of the state's 254 counties (TCE 1999). It is apparent that solutions to the pressing water quantity and quality issues in Texas and other states will require innovative approaches and technologies.

Technology currently exists to remove contaminants from produced water and to create a resource that could be used to supplement current water supplies in water-short regions. Texas A&M's Texas Water Resources Institute (TWRI)[4] is planning two projects in Texas to utilize fresh water recovered from oil field brine to rehabilitate rangelands and wildlife habitats. The program involves environmental monitoring of test plots where natural rainfall is augmented though the use of fresh water produced by portable water treatment modules. The field project is expected to show that native grasses can be re-established in degraded areas safely at a rate more than 8 times faster than comparable methods of rangeland restoration.

Several impediments to the widespread adoption and diffusion of water treatment technology such as the TWRI program must still be addressed. First, there are no market mechanisms and incentives currently in place for the oil and gas operators to treat water and make it available as a commodity. Oil and gas companies produce petroleum, not fresh water. They see the water produced with petroleum as a waste, not a byproduct to be re-used. Second, it is not clear if members of the general public are aware of the produced water technology and the potential benefits that could be derived from the development of this resource. Even if oil and gas companies began producing treated water, we do not know the extent to which individuals would be willing to accept its use.

And third, current local, state, and federal regulations classify produced water as a waste material, not a byproduct to be treated and reused. Texas A&M, like the ranchers in New Mexico[5], believes that produced water represents a resource not to be wasted.

Fresh Water Resources from an Oil Field Brine

This report discusses water management options specific to independent operators. Options such as produced water impoundment and release, re-injection, and resource recovery all are options for our industry. There are many opportunities for using produced water. However, the ability to identify an alternative as being feasible will likely be dependent upon very site-specific and situation-specific criteria. Fresh water resource recovery from produced water is the example cited in our work, but other options are available.

It is important to note that the rules and regulations relating to impoundments and the coal bed methane (CBM) industry in the West are currently being modified or developed for several states. Reviewers who can provide regulatory clarification or updates to the regulatory section of this document would be appreciated.

The impoundment of produced water from CBM production can be an option utilized by operators as part of their water management practices. In some producing basins, such as the Powder River Basin, impoundments play a large role in water management practices, while in other basins impoundments may only be used during drilling operations.

Current Regulations

Produced water is saltwater or brine that is produced along with hydrocarbons during the exploration and production processes of the petroleum industry. In some cases, the volume of water produced may exceed the volume of hydrocarbon production. The disposal of this water becomes costly to the industry. Discharge of produced water to the surface waters and seawaters is prohibited under the Clean Air and Water Act until certain criteria are met[6]. The maximum allowable amount of petroleum hydrocarbons in produced water that can be discharged is 29 ppm. Discharge of produced water is not allowed on land and in streams and rivers where the produced water may come in contact with surface water.

Regulatory Considerations Impacting BW/PW Desalination

This section of the paper discusses some of the possible regulatory requirements that would come into play if the RO concentrate is injected for either secondary recovery of hydrocarbon resources or for disposal. This analysis gives some indication of the uncertain nature of the regulatory environment and the fact that different regulators may use different regulatory mechanisms. This information has been provided by Mr. John Veil of Argonne National Laboratories and summarized in SPE 86526 [7].

The U.S. Environmental Protection Agency (EPA) administers the Underground UIC program. The UIC regulations define injection well as "a well into which fluids are being injected". A well is "a bored, drilled, or driven shaft whose depth is greater than the largest surface dimension; or, a dug hole whose depth is greater than the largest surface dimension; or, an improved sinkhole; or, a subsurface fluid distribution system". The UIC regulations place injection wells into five classes. Most Class I wells are used to inject hazardous wastes, but some Class I non-hazardous wells are used for disposal of non-hazardous materials. For Class I wells, this injection must occur below any formations that have an underground source of drinking water (USDW) within one-quarter mile of the well bore. Class II wells are used in the oil and gas industry and are particularly relevant to reinjection of RO concentrate when the source water is produced water. Class III wells are used for solution mining. Class IV wells are used to inject hazardous or radioactive wastes into or above a formation that includes a USDW within one-quarter mile of the well bore – these are banned. Finally, Class V wells include all other injection wells not placed in any of the other classes.

Table 1 indicates the responses from several states and EPA. All are consistent on scenarios 1 and 2, and all but Texas are consistent on scenario 3 – these would unequivocally be regulated as Class II wells. This follows directly from the Class II well definition shown above. Because produced water is used as source water in scenarios 1 and 2, subsequent injection of the concentrate is consistent with the first category of Class II wells (injection of fluids brought to the surface in connection with oil and gas production). Under scenario 3, the concentrate is used for enhanced recovery, thereby matching the second category of wells under the Class II definition (injection for enhanced recovery). Texas does not rule out permitting these wells as Class II, but suggests that it would need to review the determination between its Railroad Commission (the oil and gas regulatory agency) and the Commission on Environmental Quality (regulates all other environmental issues).

Scenario 4 presents a different situation because neither the source water nor the injectate meet the definition of a Class II well. Some agencies suggest that injection of the concentrate would be made into a Class I well, and the chemical characteristics of the well would determine if the well would be a hazardous or nonhazardous well. Utah suggested that injection could be made into a Class V well. The difference between Class I and Class V is quite significant. Class I wells are subject to very stringent design, construction, operation, and monitoring requirements, whereas Class V wells are regulated in a less stringent manner. The costs of constructing and operating a Class I well are much higher than comparable costs for a Class V well.

In general, the two key factors used to determine which well class would be assigned for concentrate injection under scenario 4 are the depth of the injection zone in relation to the depth of the lowermost USDW and whether the constituents of the concentrate are considered to be hazardous materials or not. If the injection occurs above or directly into a USDW and the concentrate is nonhazardous, the well could be permitted as a Class V well. Injection of hazardous concentrate into or above a USDW is prohibited. If the injection occurs below the USDW, the well would be a Class I well, and the nature of the concentrate would determine if the well would be Class I hazardous or Class I nonhazardous.

To further complicate the picture for scenario 4, California reports that if the RO concentrate is not hazardous, the Department of Oil, Gas, and Geothermal Resources may try to permit the injection as part of a Class II well. They acknowledge that in the past, the agency has occasionally authorized injection of non-oil-field wastes into Class II wells with the caveat that the permit had restrictions on total volume and the duration of the injection. If the concentrate is hazardous, its injection would require a Class I well.

Table 1. Regulatory Practices Pertaining to Re-injection of Water into Underground Formations (Burnett & *Veil*[7])

State	Produced Water		Saline Groundwater		Reference (based on emails to or phone conversations with John Veil, Argonne National Laboratory, on the dates indicated)
	Enhanced Recovery Scenario	**Disposal Scenario**	**Enhanced Recovery Scenario**	**Disposal Scenario**	
California	Class II well	Class II well	Class II well	If concentrate were not hazardous, they would consider permitting as a Class II well. If hazardous, they would use a Class I well.	Michael Stettner, California Division of Oil, Gas, and Geothermal Resources, October 6, 2003
New Mexico	Class II well	Class II well	Class II well	Depending on the characteristics of the concentrate, the well would be permitted as Class I hazardous or Class I nonhazardous.	Roger Anderson, New Mexico Oil Conservation Division, October 2, 2003
Oklahoma	Class II well	Class II Well	Class II well	Class I nonhazardous well. That would be regulated by the Oklahoma Department of Environmental Quality	Tim Baker, Oklahoma Corporation Commission, October 6, 2003; Hillary Young, Oklahoma Department of Environmental Quality, October 6, 2003.
Texas	Class II well	Class II well	In both cases, the Railroad Commission (regulates oil and gas activities) would confer with the Texas Commission on Environmental Quality. Depending on their decision the wells could be Class II or Class I		Fernando De Leon, Railroad Commission of Texas, October 6, 2003
Utah	Class II well	Class II well	Class II well	Class V well. That would be regulated by the Utah Department of Environmental Quality	Dan Jarvis, Utah Division of Oil, Gas, and Mining, October 2, 2003
U.S. EPA	Class II well	Class II well	Likely a Class II if the volume allows.	Depends on the characteristics of the concentrate and whether the injection zone was above or below a USDW.	Bruce Kobelski, U.S. EPA headquarters, Office of Groundwater and Drinking Water,

Presently, injection of RO concentrate is not a common practice. If the practice becomes more common in the future, states or the EPA may adopt new policies or regulations to govern concentrate injection.

Water Problems Caused in Part by Conflicting Regulations

Management and disposal of produced water is one of the most significant problems associated with the oil and gas industry. In Texas, more than 150,000,000 gallons of water are produced in the industry each day. The management and disposal of this water becomes very costly to the industry, as well as becoming a possible reservoir and environmental hazard. The current method commonly used throughout the petroleum industry today is reinjection of the water produced during exploration and production. This costs up to $1.50 per barrel of produced water. The preferred method for the disposal of produced water is one that adequately protects the environment and is of the lowest cost to the operator. Regulatory and monetary constraints often limit the options available, however.

The Texas Commission on Environmental Quality (TCEQ) estimates that by the year 2020, fresh water needs in the state of Texas will increase by more than twenty times[8]. There are many arid regions, such as West Texas, with little fresh water resources, but with large amounts of oil, gas, and brine production. According to the Texas Railroad Commission, an excess of 400 million gallons of water are produced from oil and gas wells in the Permian Basin of West Texas with only one percent of the produced water being used at the well locations. The remaining 99% is disposed of by reinjection. The oil and gas industry is now looking into ways of using the vast amounts of produced water to benefit these areas in which a scarcity of water exists. With new technologies in the oil and water separation and desalination processes, contaminants may be removed from produced water. This produced water may also be treated and converted into reuse quality for beneficial purposes, such as agricultural, rangeland and grassland restoration, site remediation, landscape watering, or water for oil field use. Presently, there are no clear-cut laws and regulations in the United States dealing with the beneficial use of produced water.

Section 2

Review of Current Project

Objectives & Significance of the Work

The project is a continuation of our previous SWC project and an integral part of an A&M program studying the beneficial re-use of produced water resources from oil and gas operations. Our long-term goals are to promote the more efficient management of waste water from the oil and gas industry, including produced water.
The specific objectives of this SWC project are (1) to demonstrate that treatment of oil field waste water for re-use will reduce water handling costs by reducing the need for new fresh water resources and reducing water handling and transportation costs and (2) to identify market mechanisms that provide incentives to those willing to pay the costs of developing this new and unconventional source of fresh water.

We hope to use this information and our relationships with regulatory agencies to present the case for underwriting the costs of this treatment that could provide a significant, if unconventional, new source of fresh water resources.

Description of Project

Our work included both laboratory and field testing of prototype systems and identifying practices in which environmental and oil and gas regulatory agencies can reimburse those who adopt such practices. Testing at A&M has allowed us to upgrade our existing unit and test it, first on campus at a water treatment plant then later in the field at a produced water disposal facility.

Task 1. Design and construct a system for removal of oil and other contamination materials from water used in well completion fracturing operations.

Produced brines and spent fracturing fluids contain a number of different types of ionic species, oil, colloidal particles, and heavy metals. We are testing new pre-treatment processes designed to reduce costs and maintenance and provide a more cost effective process design when compared with conventional filter train designs.

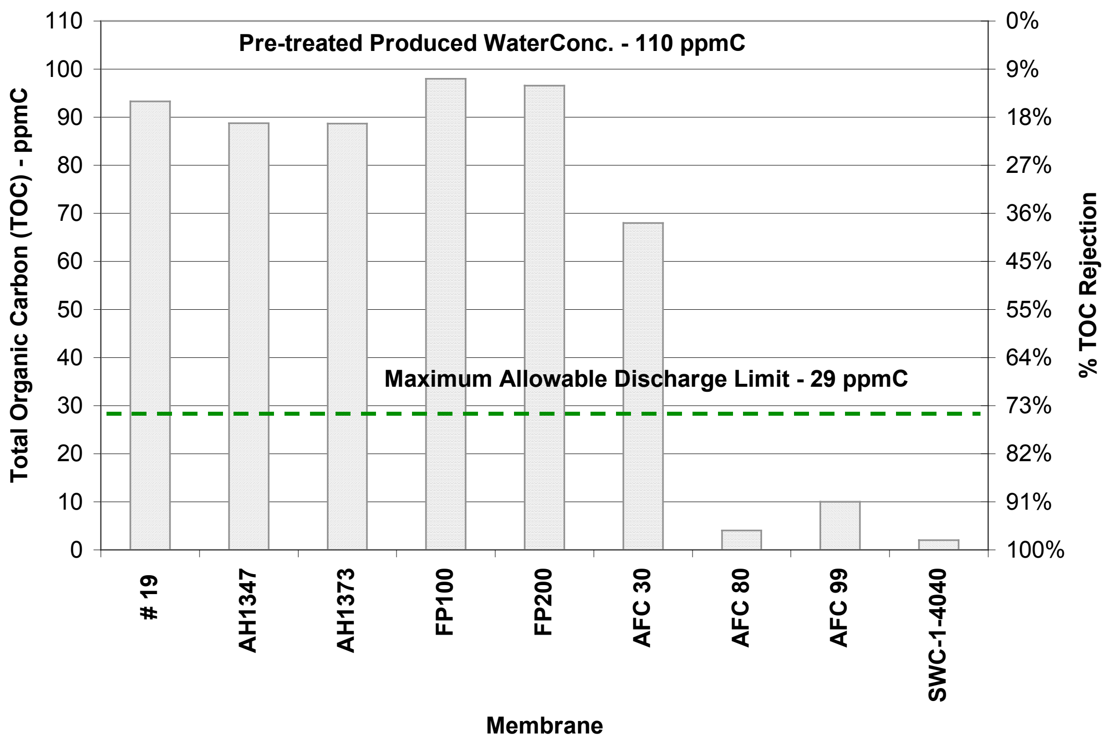
Membrane Selection Process

In early work, nine different membranes were evaluated to determine their efficiency in removing hydrocarbons and salts from the produced water[9]. Selection criterion for the membranes was based on the ability of the membrane to handle hydrocarbons and other organics, hydrophilicity, resistance to fouling by organics (oil), and rejection of dissolved solids. Membranes included one spiral, three ceramic, and five tubular membranes.

Produced water was collected from a facility located outside of College Station in Brazos County used for the disposal of produced water that is collected from the oil wells surrounding the College Station area. The produced water contained approximately 110 ppmC TOC (total organic carbon). The total dissolved solids (TDS) concentration of was about 45,000 ppm This produced water was used as feed for the membranes to determine their efficiency in removing the hydrocarbons and salts from the produced water.

Performance of these membranes are summarized in the Table.

Table 2 shows a comparison of the oil rejection characteristics of 9 types of membranes. (*Siddiqui*[9])



Based on the results of these experiments, the desalination unit was reconfigured to test pre-treatment at the water treatment facility on campus.

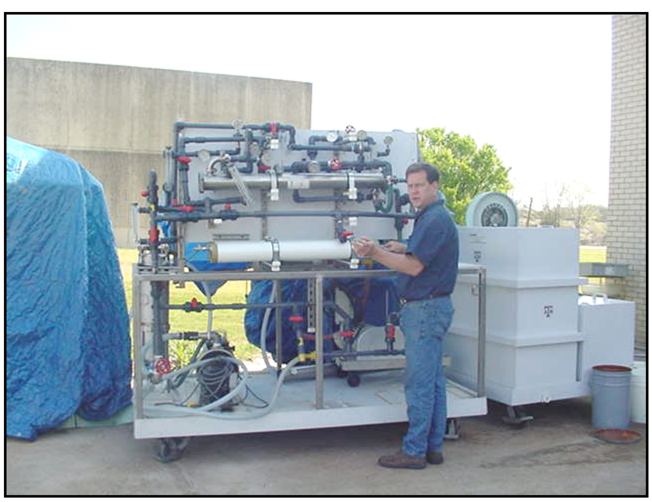


Figure 2 shows the reconfigured unit prior to loading on the desalination trailer.

A&M Desalination Unit

Components of the mobile water treatment unit were assembled and tested at Tarlton Manufacturing and at the Separation Pilot Plant on the A&M campus. The mobile unit contained a transformer to step down field electrical power from 440 v to 220v and an electrical meter to monitor power usage during testing. All electrical equipment was connected through the master panel. The trailer was quipped with three types of pre-treatment equipment including (1) a powered centrifuge, (2) organoclay absorbent canisters and (3) microfiltration crossflow membrane filtration test apparatus.

To test the mobile unit, we set up a field test at the Texas A&M Brayton Fire Fighter Training School on the west campus. This facility has several large ponds where run off water from firefighting drills collected before being recycled through the fire pumps.

Figure 3 shows the mobile unit rigged for towing to a field site.

Figure 3 shows the mobile unit configured for pre-treatment testing. At the front of the unit the power transformer steps down the power to 220 volts and monitors power usage. The center of the unit contains the portable membrane test apparatus. Behind the membrane unit sits a pair of organoclay containers while at the rear of the trailer the powered centrifuge serves to treat input water with high concentrations of suspended solids.

Figure 4 shows the unit in operation at the Brayton test site. Raw water containing biomass, oil, suspended solids, and oil are pumped through the pre-filter unit and cleaned. Cleaned water and reject concentrate were pumped back into the pond. The system worked sufficiently well that further field tests were scheduled.

Figure 4 shows the unit in operation at the firefighter training school.

Testing at the waste water pond at Brayton provided us with a better idea of how the system should operate in the field. The field trial provided performance data on (a) the powered centrifuge, (b) Performance of micro-filter membrane and (c) the performance of organoclay canisters. We also decided to redesign the microfiltration cleaning procedures after traditional methods were deemed too inefficient.

The following Table shows details of our early cleaning process.

Table 3. Cleanup of Membrane Filters

First Cleaning

Time	Pressure		Temp.	Permeate		Recir.	Retentate
	in	out		Rate(ml/sec)	Rate (gal/min)	gpm	gpm
12:00	10	4	37	23.0	**0.36**	10.38	5.32
12:07	15	10	37	50.0	**0.79**	10.18	4.55
12:14	20	15	37	78.0	**1.24**	10.25	3.43
12:16	25	22	37	108.0	**1.71**	10.25	2.8

Second Cleaning

Time	Pressure		Temp.	Permeate		Recir.	Retentate
	in	out		Rate(ml/sec)	Rate (gal/min)	gpm	gpm
1:40	10	4	37	28.5	**0.45**	10.25	5.74
1:45	15	10	37	58.5	**0.93**	10.25	4.48
1:48	20	16	37	86.5	**1.37**	10.18	3.29
1:52	25	22	37	110.0	**1.74**	10.25	2.38

Third Cleaning

Time	Pressure		Temp.	Permeate		Recir.	Retentate
	in	out		Rate(ml/sec)	Rate (gal/min)	gpm	gpm
3:50	10	5	38	26.0	**0.41**	10.18	5.74
3:55	15	11	38	60.0	**0.95**	10.18	4.41
3:57	20	15	38	83.0	**1.32**	10.117	3.29
4:00	25	20	38	112.5	**1.78**	10.18	2.45

Because of the importance of keeping membranes clean, a new research project has been created to develop new cleaning methods for membranes. Details of that program are at www.gpri.org (brine treatment).

Task 2. Evaluate desalination performance in extended tests.

Task 2 included tests on the field unit operation, first at the A&M campus site, then in Decatur Texas at Key Energy Denton Creek disposal facility. The field facilities support Burlington Resources and other operator's Barnett Shale fracturing operations.

Figure 5 shows trucks queuing at the Denton Creek facility unloading dock. The site (in 2004) received as many as 40 trucks a day representing more than 5,000 bbl brine disposed per day.

Figure 5. Brine transport trucks waiting to unload at the Denton Creek facility. At one time in late 2004, the Texas Railroad Commission had received more than 40 applications for disposal well operations in Wise County Texas.

The desalination trailer was taken to the Denton Creek facility and tested in December of 2004. It had been modified to the new test conditions expected at the site. The trailer is shown in Figure 6. A 250 gallon polyethylene water tank replaced the powered centrifuges unit and a large tool box (red container) was placed on the trailer to serve as a storage and tool locker. Desalination operations were performed under the supervision of Mr. Carl Vavra of the Separation Sciences section of the Texas A&M Food Protein Research Center.

Figure 6. Desalination trailer at Denton Creek. Fresh water had to be transported to the site to ensure cleaning and startup would not damage the membranes.

Our milestone goal for these extended duration tests had been to process at least 1,000,000 gallons of brine in order to obtain accurate data on power requirements and membrane fouling. The tests were stopped early (100,000 gallons processed) because of a mechanical failure unassociated with membrane performance. However sufficient information was collected to classify the test as a success. The following Table contains test data from our laboratory and field tests and from a field pilot performed by NATCO Oil Field Services (Frankowicz and Lee [10]).

Table 4. Recovery efficiency and operating cost of membrane treatment.

Process Description	Membrane Type, (TMP[a])	Brine composition, TDS	Recovery efficiency,%, (Q, gpm)	Operating Costs $/1,000 gallons
Pre-treatment	Microfiltration, 25 psi	Fresh water with TSS, oil, & biofilm	20% (3.2)	$0.84
Desalination[b] (single stage)	"Open" RO, (235)	Simulated brackish water	1%,).02 est.	NR
Pre-treatment	Microfiltration, (45 psi)	20,000 TDS oil field brine	25%, (2.5)	$3.24
Pre-treatment (dual stage)	Microfiltration, (45 psi)	20,000 TDS oil field brine	25%, (5)	$1.27
Desalination (single stage)	RO seawater (650)	12,000 TDS oil field brine	3.5% (.28)	$12.55
Pre-treatment (dual stage)	Ultrafiltration (50 psi)	NR	NR	$0.50
a = transmembrane pressure, psi b= small scale system test on simulated brine. No operating costs determined.				

The Table shows information from both pre-treatment and from RO desalination. In addition it contains comparison data from "single stage" and "dual stage" tests. The dual stage tests were conducted with parallel filters in line, taking advantage of flux across filters and relatively low permeate flows.

The NATCO tests were performed in 2004 using produced water from a lease near Crane, Texas. The objective of the tests was to condition produced brine that was to be re-injected into an oil bearing formation. The Ultrafiltration membrane used had an open area cross section of 0.1 micron opening. The tests were successful and the operator is considering a 25,000 bpd facility.

Task 3. Documentation & Technical Transfer

Texas A&M TEES Communications was our partner in this project and served as the spokesman for the project. The project is supported externally by the GWPC and GPRI. The project has received favorable publicity. In 2003 and 2004 Burnett gave presentations to the American Association of Petroleum Geologists (AAPG), the city Council of San Angelo Texas, the American Membrane Technology Association (AMTA), the City of El Paso Membrane Pre-Treatment Workshop, the United Nations Food and agriculture Organization (FAO), and the Society of Petroleum Engineers.

In addition A&M has been featured in the Schlumberger Technical Journal (2004 1Q), the American Oil and Gas Reporter (March, 2005), and the Saudi Aramco Technology Journal (2003). In 2005, the magazine *Landscapes* will feature desalination as an option for Texas agriculture (*Landscapes* is published by the Texas A&M University System for the Agriculture College and has a circulation in excess of 16,000 copies.)

Burnett has also given technical presentations at four SWC regional technology transfer workshops and participated in the 2004 technology exchange in Oklahoma City sponsored by the Oklahoma Marginal Wells Commission.

Task 4. Identify Reimbursement Mechanisms

We have worked to identify market based mechanisms to encourage those who employ these new operating practices. As an example of the type of incentives that could be employed, the Texas Legislature is creating incentives for those who develop unconventional sources of fresh water resources. The 2005 Texas Legislature is considering two bills proposed by State Senator Armbruster to provide funding for alternative water supply facilities and for desalination of seawater and brackish ground wate[11]. There is to be a tax subsidy available that can offset costs of constructing desalination facilities that supply fresh water to communities in water starved areas of the state. Such measures are a continuation of the type of incentive created by the state of New Mexico that provides a bounty of $1,000 Ac. Ft of water treated and released into the Pecos River watershed.

Section 3

Results of Study

While we do not have long-term operating performance on the systems (goal was 1,000,000 gallons of water processed) we believe that the operating costs and performance of the units have been well characterized and that the process design has been fully proven.

We still anticipate that the new A&M process designs will reduce operating costs of the desalination units significantly. This would show that a marketable resource, fresh water can be recovered from oil field brines, avoiding the expense of water transport to field sites. The expected **operating cost** of the units are expected to be from $0.15 to $0.25 per barrel ($70 to $150 per day for a 20,000 gwpd unit).

Fresh water recovered from the water treatment units can be used to remediate sites that have been spoiled by oil or brine spills offering tremendous potential cost savings. The State of Texas budget in 2002 for oil field cleanup was more than $20,000,000[3]. This money is for cleaning up oilfield sites (more than 600) and to plug abandoned wells (more than 18,000). Improved cleanup techniques and faster remediation offers the promise to save millions of dollars in Texas alone.

Beneficial Use of Desalinated Oil Field Brine

Areas in West Texas with significant oil and gas production (and brine production) will be the most likely candidates for beneficial use of produced water. Municipal use of produced water desalination (PWDS) technology might possibly be a beneficial use of the resource. Distribution and/or storage of desalinated water, either in surface lakes and ponds or in subsurface aquifers, are a significant issue that must be considered when evaluating PWDS economics. Technology is available that allows pre and post-treatment required to assimilate or blend desalinated water into the local water supply system. For example, Odessa's average daily water use the last two years has been 12 million gallons/day in winter and 29.5 million gallons/day in summer, with a peak of 34.9 million gallons used on June 26, 2002. The difference in water use in the summer is predominately landscape irrigation. Corresponding daily brine disposal in Ector, and neighboring Midland, and Winkler Counties Texas in 2002 has been slightly more than 4,000,000 gallons of water per day according to TWDB records, or 25% of the water used on landscape irrigation in the city[12]. Most other areas of Texas reflect the same water usage.

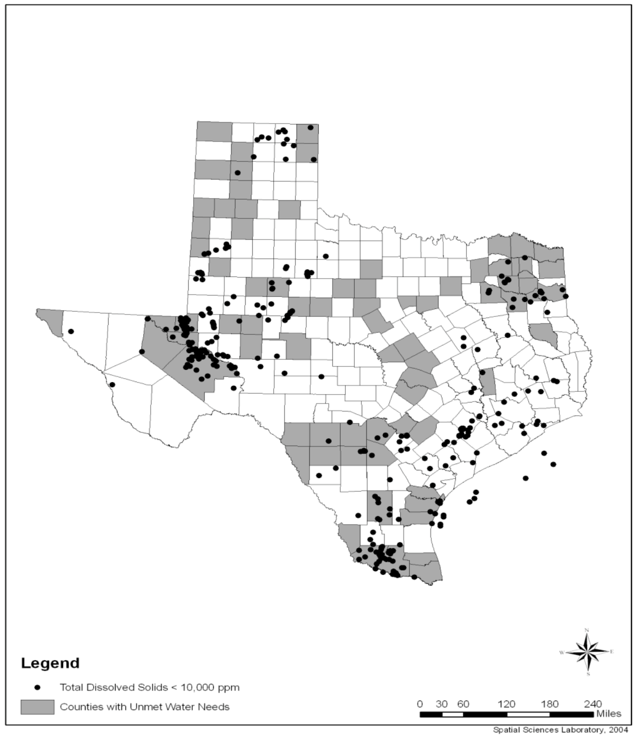


Figure 7 shows the distribution of brackish produced water sites in the USGS database for Texas. The brines are shown with EPA classified counties with unmet water needs[13,14].

Many areas of the state have unmet water needs. Additionally TWDB anticipates a significant increase in demand for fresh water resources in the next 20 years. These socioeconomic factors indicate that should be significant potential for uses of water produced from oil field brine if the fresh water recovered meets the applicable regulations that such usage requires.

Universities have been investigating the potential for rangeland and habitat restoration programs in West Texas, the use of brackish water for growth of crops and the study of salt-tolerant plants[17]. The results of analyses focusing on restoration of rangeland systems may provide a prioritization where habitat enhancement would be most efficient. Of significant interest will be the development of cooperative programs with other environmental agencies and introduction of the technology to determine their opinions on use and acceptance. Hand in hand with this opportunity is the potential to use desalination as a way of enhancing the quality of impaired streams in Texas.

Potable Uses

As mentioned above, the highest level of water treatment is associated with human ingestion. The Texas Commission on Environmental Quality has responsibility for the quality of water discharged into the public sector. A project involving potable use of treated brine produced by oil and/or gas wells would receive extreme scrutiny by the TCEQ. However, if the requirements of the applicable regulations were met, the State would review the information submitted to confirm there were adequate safeguards[15].

The applicable TCEQ Rule pertaining to public drinking water systems is TAC Chapter 290, Section 42(g). This section states that "other" treatment processes will be considered on an individual basis. Based on input from TCEQ staff, a licensed professional engineer must provide "pilot test data or data collected at similar full-scale operations" of the proposed system demonstrating that the system would meet applicable Drinking Water Standards. The pilot test must be representative of the actual operating conditions that can be expected over the course of a year, meaning the test must be done during the time of the year that would place the most strain on the treatment system. Additionally, proof of a one-year manufacturer's performance warrantee or guarantee assuring the plant will produce treated water that meets minimum state and federal drinking water standards is commonly required by the State as a condition of an operating permit.

Therefore, if this water was to be used as an independent potable water source, among other drinking water standards, TDS levels must be reduced to the Environmental Protection Agency's secondary standard of 500 mg/L. Permitting for waters with a TDS greater than 500 mg/L may be available if this water is the only potential potable resource for a community. However, if the high TDS water were to be blended with another public water supply (PWS) and then distributed, the required level of treatment could be less.

Discharge to Supplement In stream Flow

Discharges to surface water designated as Waters of the State must meet Texas Surface Water Quality Standards (TSWQS) as contained[6] in TAC Chapter 307.Without a specific stream or amount of discharge set, it is difficult to outline all necessary regulations one must follow. The permitting process, done through the TCEQ Water Quality Division, is conditional on two key variables, the receiving stream ambient quality and the volume of the discharge. The TSWQS identify individual water quality standards for each stream in the State, and these standards are based on the use category a particular stream is assigned. A discharge, once dilution has occurred, must not hinder the water quality standards set for the receiving stream.

TCEQ Guidance Document RG-194, *Procedures to Implement the Texas Water Quality Standards*, provides a section entitled, "Screening Procedures and Permit Limits for Total Dissolved Solids" states, "Concentrations and relative ratios of dissolved minerals such as chloride and sulfate that compose total dissolved solids (TDS) will be maintained to protect existing and attainable uses". The screening procedure is applied to all domestic dischargers with an average permitted flow of 1 million gallons per day (MGD), all industrial majors, and all industrial minors that discharge process water. The screening procedure is divided into categories based on the type of receiving stream: intermittent stream, perennial stream, intermittent stream within three miles of a perennial stream or intermittent stream with perennial pools, lake, and bay or wide tidal river. The equations used take the following into consideration:

- TDS criterion of the receiving stream (as defined in the TSWQS)
- Harmonic mean flow of the receiving stream
- Effluent flow volume
- Effluent TDS concentration
- Effluent concentration at the edge of the human health mixing zone

For discharges to freshwater, a screening procedure is used to determine whether a total dissolved solids (TDS) permit limit or further study of the receiving water is required. If screening demonstrates elevated levels of TDS, then appropriate permit limits are calculated. The following Figure developed by TWRI outlines potential sites.

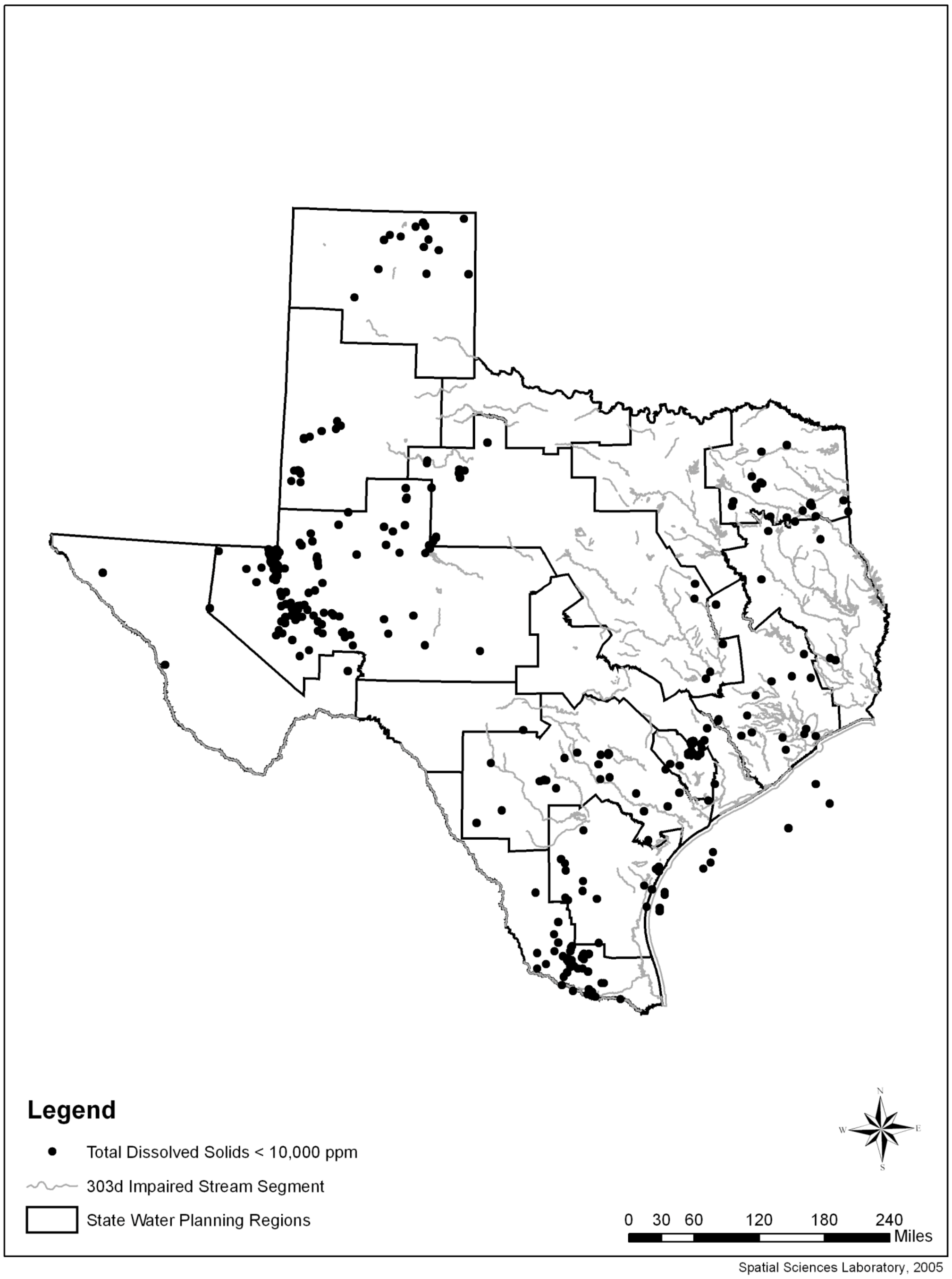


Figure 8 Locations in Texas where brackish produced water production is near streams impacted by poor water quality. The dark outlines are Texas Water Districts.

Livestock Uses

Another potential use of the brine-produced water is livestock drinking water. There are very little, if any, regulations to follow for this potential beneficial use.. If the owner of the livestock is amenable to using a water supply, he is allowed to do so. A typical rule of thumb, though, is a TDS limit of 6,000 mg/L for this purpose. This is the TDS concentration TCEQ employees use when gauging if a particular stream is suitable for livestock use. In many areas of West Texas, surface water supplies approach this level.

Irrigation of Rangelands and Habitat Restoration

Necessary treatment levels of water to be used for crops and grasses irrigation is driven by the salt tolerance of the crop or landscape. The landowner must know the drainage characteristics of his soil, its SAR (Sodium adsorption ratio), and the type of grass or other plants to be sustained. (The sodium adsorption ratio measures the relative proportion of sodium ions in a water sample to those of calcium and magnesium. The SAR is used to predict the sodium hazard of high carbonate waters especially if they contain no residual alkali.)

Care must also be taken to avoid salt buildup if drainage is marginal. Information received from the Texas A&M Soil and Crop Sciences department has provided the following information on salinity tolerance of turf grass:

Table 5. Salt Tolerance of Various Grasses (Potential Uses of Water Produced from Brine)

Common Name	Threshold TDS[1]	50% Growth[2]
Bermuda grass	Less than 960	8,800
Creeping Bentgrass	0 to 1,920	-
Kentucky Bluegrass	0 to 1,920	1,920 to 2,560
Perennial Ryegrass	1,920 to 8,000	6,400 to 8,000
Seashore Papsalum	Less than 960	14,400
St. Augustine grass	Less than 960	18,400

1. TDS level at which the grass begins to slow growth due to salts.
2. TDS level at which growth is slowed to 50% of that in salt free environment.

Additionally, when irrigating with something considered reclaimed water, care must be taken regarding the potential for runoff to Waters of the State. This must be avoided with the use of best management practices.

Aquifer Recharge

Aquifer Storage and Recovery (ASR) refers to the storage or banking of fresh water in aquifers. ASR is a water resources management technique for actively storing water underground for recovery and use when needed (ref xx). "Conjunctive use" and "artificial recharge" are sometimes used interchangeably. Conjunctive use is a combination of practices to make the best use of surface water during wet periods and ground water during dry periods, but does not necessarily imply active water storage practices used in ASR. Artificial recharge (AR) is actively moving water into ground-water systems. AR can be seen as the storage part of aquifer storage and recovery.

ASR offers advantages over surface-water reservoirs in terms of construction costs, environmental effects, evaporative loss of water, water eutrophication, reservoir induced earthquakes, potential for catastrophic failure, and proximity to users. Most ASR projects are associated with large water treatment operations where fresh water can be stored in the aquifer in times of low water demand, to be pumped out in times of high demand. . Currently, there are a number of ASR facilities operating in Florida with more planned.[18,19],

ASR for the fresh water production from oil field brine has not been proposed. Use of treated brine for aquifer recharge could increase groundwater availability. However, if the water is to be stored in a potable aquifer zone, the rule of thumb is that the water must be treated to drinking water standards. One potential attraction for aquifer recharge is that it could be used for water rights transfer from party to party. Such offsets are accepted in the Columbia River Basin in Oregon and Washington where a one-to one- replacement of fresh water is required for permits to be issued for new fresh water usage[20]. In effect, a potential user of the fresh water from the aquifer can provide a “one-for-one” gallon replacement into the aquifer from fresh water injection at another location. The aquifer would necessarily need to be unitized for this eventuality. An analogy is with oil and gas producing properties where unitization of fields is the norm rather than the exception. All of these scenarios would require some form of regulatory reform.

Potential for Saline Water for Oil Field Use

The oil and gas industry uses large amounts of water for daily operations. Brines are used to formulate drilling fluids, kill fluids, cementing fluids, completion fluids, and fracturing fluids. The prime requirement for these systems is that the brines must be consistent in quality and not have any material that might cause compatibility problems. Practically speaking, this means that the brines should be of neutral pH, have minimal hardness and, if iron is present; it must be stabilized in a soluble form.

Since pre-treatment of brine is a major part of the A&M program, we have worked to condition various brines using microfiltration and ultrafiltration to remove contaminants. Field testing at Denton Creek provided a test case. Table 2 showed power usage vs. water treated for saline produced brine. Operating costs (based upon $0.07 per Kwh) have been estimated between $1.27 and $3.24 per 1,000 gallons of brine treated.

We found that this cost of low-pressure membrane treatment to condition brine was a practical option, however the resulting brines are not stable for long periods of time and will require iron chelants. Further work is needed to determine compatibility of such systems in oil field brine uses for other purposes.

As an example of the cost savings, Table 6 shows a worksheet prepared with the assistance of Devon Energy[21]. The Table shows a cost savings of over $38,000 per well if water could be re-used rather transported off-site to a disposal well.

Table 6. Potential for Savings with Use of Treated Brine for Fracturing Operations

Fracturing Operations-Current Practices						
Step No.	Description	Volume		Cost of the step	subtotal cost	
		bbls	gallons	$/bbls		
1	Water Transport to Well	18,000	756,000	$ 1.35	$24,300.00	
2	Frac Water Treatment on site	-	-	$ 0.01	$0.00	
3	Water to Well 2	-	-	$ 1.00	$0.00	
4	Water to Disposal Well	18,000	756,000	$ 1.00	$18,000.00	
5	Disposal costs	18,000	756,000	$ 0.35	$6,300.00	
				Total costs	**$48,600.00**	
	Demineralization with UF to remove TSS, biofilm, and scaling materials					
		Comparison of Costs		BBls treated =	18,000	**$ Savings per well**
		Existing Practices			$ 48,600	
		Pre-Treatment & Desalination			$ 47,448	$1,152
		Pre-Treatment only			$ 10,044	$38,556

Potential for Use in Waterflooding Operations as Make-up Brine

General Regulatory Requirements Relating to Beneficial Use

The regulations applicable to this type of source water are not clearly defined. According to the Texas Commission on Environmental Quality (TCEQ) staff, this water would be considered an Industrial Reclaimed Water, and would, therefore, be subject to all rules relevant to the use of industrial reclaimed water (Texas Administrative Code, Chapter 210, Subchapter E, and Special Requirements for use of Industrial Reclaimed Water).

Additionally, any proposed use of industrial reclaimed water not considered “on-site” must comply with numerous other general reclaimed water requirements, including the sampling and analysis frequency. For Type I reuse, those uses where human contact is likely, the water must be sampled for applicable parameters, which depend on the applicable use, twice per week. For uses considered Type II, those uses where human contact is unlikely, the water must be sampled for applicable parameters once per week.

Source water quality is of great concern, particularly when the end use will be potable. Any system providing drinking water to more than 25 people must meet restrictions on the amount of pollutants allowed in the drinking water system. Due to the concern regarding contaminants that exist in the source water, as well as potential precipitation, fouling, and scaling of the membranes, a study conducted for the Nueces River Authority suggested source waters high in salt content be tested for 27 different parameters prior to the planning of a treatment facility (HDR, 2000).

Because the rules regarding this type of water source are not clearly defined, regulatory staff suggested that, once a project is defined, an official letter be sent to the State to inquire about all relevant regulations and permits necessary

Barriers to Adoption of Produced Water Desalination

Our program has been well received by industry and the government. In Texas, the Governor and the Texas Water Development Board (TWDB) have been providing leadership for the state in developing desalination programs, including treatment of waste water and oil field brine. However, environmental and regulatory issues related to desalination of produced water in Texas clearly inhibit technology advancement of this resource. Cost reduction advancements in technology are slowed by a lack of a clear "path to market" of new products and processes. It is hoped that this SWC project willo add a different perspective to discussions about water sources for desalination, conveyance issues associated with water transfer, and the demand for the resource if it were to be made available.

Local issues that communities would identify as barriers must be addressed at the local level. Barriers include the perception that desalinated produced water is not pure enough for consumption by humans or livestock and that there might be environmental drawbacks to its use for plants, range, and habitat sustainability. It is suggested however that advanced technology and an improved regulatory climate will increase the likelihood of adoption of PWDS by water use groups in the state.

The Texas A&M program is sponsored by the Stripper Well Consortium (SWC), the Global Petroleum Research Institute (GPRI), and by the Texas Water Resources Institute (TWRI) It is endorsed by the Texas Railroad Commission, the agency responsible for regulating the oil and gas industry in Texas.

References

1. Gould, Andrew, “*Technology and Production, A View for the Future*,” Keynote Address at the 35th annual Offshore Technology Conference (OTC), May 4, 2004, Houston. TX.
2. Texas Railroad Commission URL Http://www.rrc.state.tx.us
3. Texas A&M Cooperative Extension http://texasextension.tamu.edu/ag_nr.html
4. Texas Water Resources Institute http://twri.tamu.edu
5. Soussan, Tania, “Ranchers, Indians Sue BLM over Wells in Otero Mesa, New Mexico,” The Albuquerque Journal, Feb. 5, 2005.
6. Veil, John A.; Puder, Markus; Elcock, Deborah; Redweik, Jr., Robert A White Paper Describing Produced Water from Production of Crude Oil, Natural Gas, and Coal Bed Methane
7. Burnett, D. B. and Veil, John A. “Decision and Risk Analysis Study of the Injection of Desalination Byproducts into Oil and Gas Producing Zones,” SPE 86526, presented at the SPE Formation Damage Conference Lafayette, LA, 13-14 Feb. 2004.
8. Texas Commission on Environmental Quality http://www.tceq.state.tx.us
9. Siddiqui, Mustafa, “Treatment of Oil Field Brine by Desalination: A Multidisciplinary Program”, MS. Thesis Department of Petroleum Engineering, Texas A&M University, 2002
10. Frankowicz, T.F. and Lee, J. “Treatment of Produced Water with an Ultrafiltration Membrane- A Field Trial,” presented at the 14th Annual Produced Water Seminar, January, 2005.
11. Houston Chronicle (Clay Robison) “Legislation to make major changes in state water policy), April 6, 2005.
12. Texas Water Development Board http://www.twdb.state.tx.us “*Water for Texas 2002 Plan*” http://www.twdb.state.tx.us/publications/reports/state_water_plan/2002/finalwa erplan2002.htm
13. United States Geological Society URL http://www.usgs.gov
14. Compendium of West Texas Oil Fields, Vol. I-VII, West Texas Geological Society, Midland TX Library Reference Shelves.
15. Burnett “*Private Conversation*” Devon Energy, October, 2004.
16. Theodori, Gene L., and Fox, Wm. E. “Fresh Water Resources from Oil Field Brine: Developing and Implementing Market Mechanisms and Incentives,” TWRI proposal, March 2002.
17. Swain, Walter. “ Aquifer Storage and Re-Use in California”, http://ca.water.usgs.gov/issues/6.html
18. Vecchioli, John Aquifer Storage and Recovery in South Florida, U.S.G.S. presentation at the South Florida Restoration Science Program, 2003.

19. Nguyen, Phong D. and. Mueller, Thomas K. "A Cautious Look at Aquifer Storage Recovery in South Florida from a Public Health Viewpoint," Florida Water Resources Journal • December, 1996.
20. "Columbia River Initiative, Columbia River Mainstream Water Management Program" Washington State Department of Ecology , http://www.ecy.wa.gov/ecyhome.html

21. Burnett, David B. "Private Correspondance, " October, 2004